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Fail-Safe Transfer Line for Hazardous Fluids

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FAIL-SAFE TRANSFER LINE FOR HAZARDOUS FLUIDS

by

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Contract No. 68-03-2039

Project Officer

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16. ABSTRACT

The design principles, development, laboratory testing, fabrication and field testing of a fail-safe transfer line for hazardous liquids are described. The system provides a 2-inch-ID flexible hose line for off-loading tank cars or trucks and detects leaks by monitoring flow inventory with corrosion-resistant, turbine-type flow meters at the inlet and outlet ends. Reliable shutdown of the line at leak rates as low as 1% of flow is achieved. As an example, at a flow of 6 liters/sec (100 gal/min), shutdown occurred within 8 sec with a fluid loss of less than 500 ml (1 pint). The line is also automatically shut down immediately when electrical power or valve actuator pressure is lost, when any sensor or control cable is severed, or when there is a major difference (>6.5%) between the metered input and output flows. The system meets the National Electrical Code explosion-proof standards for Class I, Division I, Group C or D environments. Use-demonstration tests at a chemical plant were satisfactory except for occasional fouling of the flow meters with material that solidified in the transfer hose between operations. The system is recommended for use with material that remains in a liquid state under all normal conditions.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report describes the design, development, and use-demonstration of a fail-safe transfer line for the transfer of hazardous fluids between storage facilities and railroad cars or tank trucks. Installation of the system and its trial use were performed by the management and operating personnel of the Goodyear Synthetic Rubber Plant, Houston, Texas. This report may be of interest to manufacturers, shippers, and users of liquid chemicals that are either hazardous materials or potential pollutants.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The design principles, development, laboratory testing and fabrication of a fail-safe transfer line for hazardous liquids are described.

The system incorporates a 2-in.-ID flexible hose line for offloading tank cars or trucks and detects leaks by monitoring flow inventory with turbine-type flow meters at the inlet and outlet ends. Reliable shutdown of the line at leak rates as low as 1% of flow is achieved. As an example, at a flow of 6 liters/sec (100 gal/min), shutdown occurred within 8 sec with a fluid loss of less than 500 ml (1 pint). The line is also automatically shut down immediately when electrical power or valve actuator pressure is lost, when any sensor or control cable is severed, or when there is an excessive difference ($>6.5\%$) between the metered input and output flows. The system implemented was designed to meet the National Electrical Code explosion-proof standard for use in a Class I, Division I, Group C or D environment. Use-demonstration tests at a chemical plant were satisfactory except for occasional fouling of the flow meters with material that solidified in the transfer hose between operations. The system is recommended for use with material that remains in a liquid state under all normal conditions.

This report was submitted in fulfillment of Contract No. 68-03-2039 by Science Applications, Incorporated (SAI) under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 24, 1975 to June 30, 1981 and work was completed as of August 4, 1981.

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SECTION I

INTRODUCTION

OBJECTIVE

The objective of the project described in this report was to develop a fail-safe transfer line for hazardous liquids. The principal requirement was the reliable, automatic shut down of a transfer line in response to a leak well below the magnitude that could be controlled by an excess flow valve (rising ball type). Additional requirements included shut down of both ends of a leaking or severed line to prevent back-siphoning, shut down of the line when any of the conditions necessary for its reliable operation (e.g., electrical power, air pressure) were not satisfied, a means to verify operability at time of use, and the ability to handle any type of hazardous liquid. The entire system was to be constructed from off-the-shelf components of standard industrial quality.

The application addressed was the loading and unloading of railroad tank cars and tank trucks.

SCOPE

The project encompassed four areas of effort:

a. Systems Design. This task involved the analysis of alternative methods for sensing leaks and the design of all components for the transfer line. The governing criteria were reliability, cost, and compatibility with the hazardous materials to be handled in the "Use-Demonstration Tests".

b. Assembly and Development Tests. This task included the acquisition of all components, construction of the line, and testing of the line in a controlled environment using water as the liquid. During the development phase, the design was optimized to achieve the best practical capability for detection of small leaks.

c. Use-Demonstration Tests. In this task, the line was used in an industrial environment, at the Goodyear synthetic rubber plant in Houston, Texas, to offload railroad tank cars of "TAMOL-L", an aqueous solution of the sodium salt of a napthalene sulfonic acid.

d. Analysis and Reports. This task included analysis of data and the preparation of monthly and final reports.

NEED

Application of this transfer line or its principle to all loadings and offloadings of hazardous and polluting liquids could result in a significant reduction in the number of spills. According to a study of reported spills of hazardous materials in the United States during the period of January 1, 1971 to June 30, 1973, the failure of a hose or transfer line resulted in 92 spills or 7% of the total of all spills reported (1). Similarly, an analysis of spills of bulk liquids at United States marine terminals during 1974 and the first 8 months of 1975 revealed that 7.5% of all spills (108 out of 1441) during cargo transfer operations resulted from the failure of the hose or pipeline (2). These data, when combined with the frequency of loading and offloading operations, indicate that one spill results from a hose or pipe failure in every 1,000 transfers. For all causes of spills at marine terminals during loading and offloading bulk liquid cargos, the spillage rate is approximately 12 per 1,000 operations (3).

SECTION 2

SUMMARY

The requirements for the transfer system included the reliable detection of small leaks, well below the levels controllable by rising-ball-type check valves, and automatic shut-down of the transfer line on detection of a leak. An inventory balance approach to leak detection was used by comparing flow-rates into and out of the line. Analysis and experimentation eliminated thermistors and thermal probes as suitable flow sensors, and the system was built using turbine-type flow meters.

A digital circuit monitors the indications from the two flow meters. Two parameters, selectable by the system user but not accessible to the operator, permit adjustment of the system to balance the probability of small leak detections vs. false alarm rate. The first parameter is a leak threshold level and the second a shutdown decision point. Whenever the flow imbalance exceeds the preset threshold valve, a leak condition is logged. Whenever the number of successive leak indications (with no more than one intervening "normal" indication) exceeds the shutdown decision point, the circuit causes closure of air-actuated valves at both ends of the line.

Leaks as small as 1% of flow are reliably detected. Smaller leaks are also readily detectable, but with the risk of false alarms.

A relatively elaborate treatment of flow imbalance measurement was necessary to permit detection of small leaks in the presence of naturally occurring flow variations (hose elasticity, gas bubbles, etc.).

The system fabricated included a 50-ft, 2-in.-ID hose with stainless steel inlet and outlet assemblies. Air-actuated valves were selected for their light weight and reliability. Air reservoirs were incorporated at each end to ensure shutdown should line pressure be lost.

The system was tested at the Goodyear synthetic rubber plant at Houston, Texas. It was used to offload railroad tank cars containing TAMOL-L, an aqueous solution of the sodium salt of napthalene sulfonic acid. The tests were mainly successful. However, between transfer operations, the fluid coagulated into a semi-solid mass upon prolonged exposure to the atmosphere, and the inside of the line became coated with this material. Upon the next use of the hose, the solidified material gradually sloughed off and frequently fouled the flow meter at the outlet end for periods long enough to initiate shutdown. Twenty minutes of flow were required to clear the line of this condition on one occasion.

On another occasion, a flow meter became clogged with a solid mass of the material and had to be disassembled and cleaned.

However, the system functioned as designed when the line was "clear" and, in its connections and use, did not impose any significant problems upon normal operations at the Goodyear plant.

SECTION 3

CONCLUSIONS AND RECOMMENDATIONS

The detection of all leaks above a threshold level on the order of 1% of flow rate in a liquid transfer line between storage facilities and tank cars or tank trucks is feasible using a flow balance comparison system constructed of commonly available components. Rapid, automatic closure of both ends of the line upon detection of small leaks is simple to accomplish. Occurrence of major leaks (> 6.5% of flow) causes shutdown within a few seconds.

Naturally occurring variations in volumetric flow, presumably caused by entrained compressible gases, flow cavitation, and the elasticity of the transfer line, preclude the reliable detection of small leaks (within the tolerance of the flow sensors) on a single event basis.

The fail-safe system for the automatic shut-down of a transfer line in response to a small leak is relatively cumbersome when built with standard discrete components. A significant portion of the size and weight results from the need for pipe-unions, nipples, couplers, junction boxes, and other items needed to integrate the components. Re-engineering is recommended.

A fail-safe transfer system that embodies the features of the system described in this report is applicable to nearly any transfer line or conduit handling non-compressible fluids with a viscosity and flow rate within the operating range of available turbine flow meters. The size of the line and the materials used may be varied to suit different flow rates and fluids. Hazardous materials in the National Electrical Code Class 1, Division 1, Groups A and B (4) impose a requirement for different types of valve actuators since electrically-operated pilot valves for these categories of materials are not commercially available.

Reliable detection of leaks by flow comparison is not feasible with thermal probe flow sensors in fluids which contain even microscopic undissolved solids. These tend to foul the sensors.

Fluids that leave a solid or semi-solid residue upon evaporation of the liquid require that the tranfer line be flushed after each use. Storage of the line with the ends sealed is recommended.

The size, weight, and cost of a system comparable to the one described in this report can be significantly reduced by the development of inlet and outlet modules that have integral valves, activators, pilot valves, flow meters, junction boxes, etc., and the development and certification

of an intrinsically safe control module. Implementation of these changes and alterations is not economically practical for systems manufactured in small quantities. However, the prototype system was deemed usable without special handling equipment by product transfer personnel at the industrial plant where the system was evaluated.

A fail-safe transfer system, functionally similar to that described in this report, should be considered for use in the transfer of particularly hazardous materials between storage facilities and tank cars and tank trucks.

SECTION 4

DESIGN, DEVELOPMENT, AND USE-DEMONSTRATION

ANALYSIS AND DESIGN

The analysis and design task involved two principal activities. The first was the selection of the components, materials, and techniques to be used in the system, and the second was the detailed design for the assembly of these components. Experience gained during the assembly and development phase led to a number of design changes and refinements that did not alter the basic concept. These changes and refinements are described in subsequent paragraphs.

The basic concept is illustrated in Figure 1. A flexible transfer line is equipped with essentially identical inlet and outlet assemblies. Each assembly contains a fast acting, remotely operated valve and a device to measure fluid flow. A control module compares the flow measurements at each end. Upon detection of a flow imbalance, the control module automatically causes the valves at each end to close. In addition to flow comparison, the system incorporates other fail-safe features:

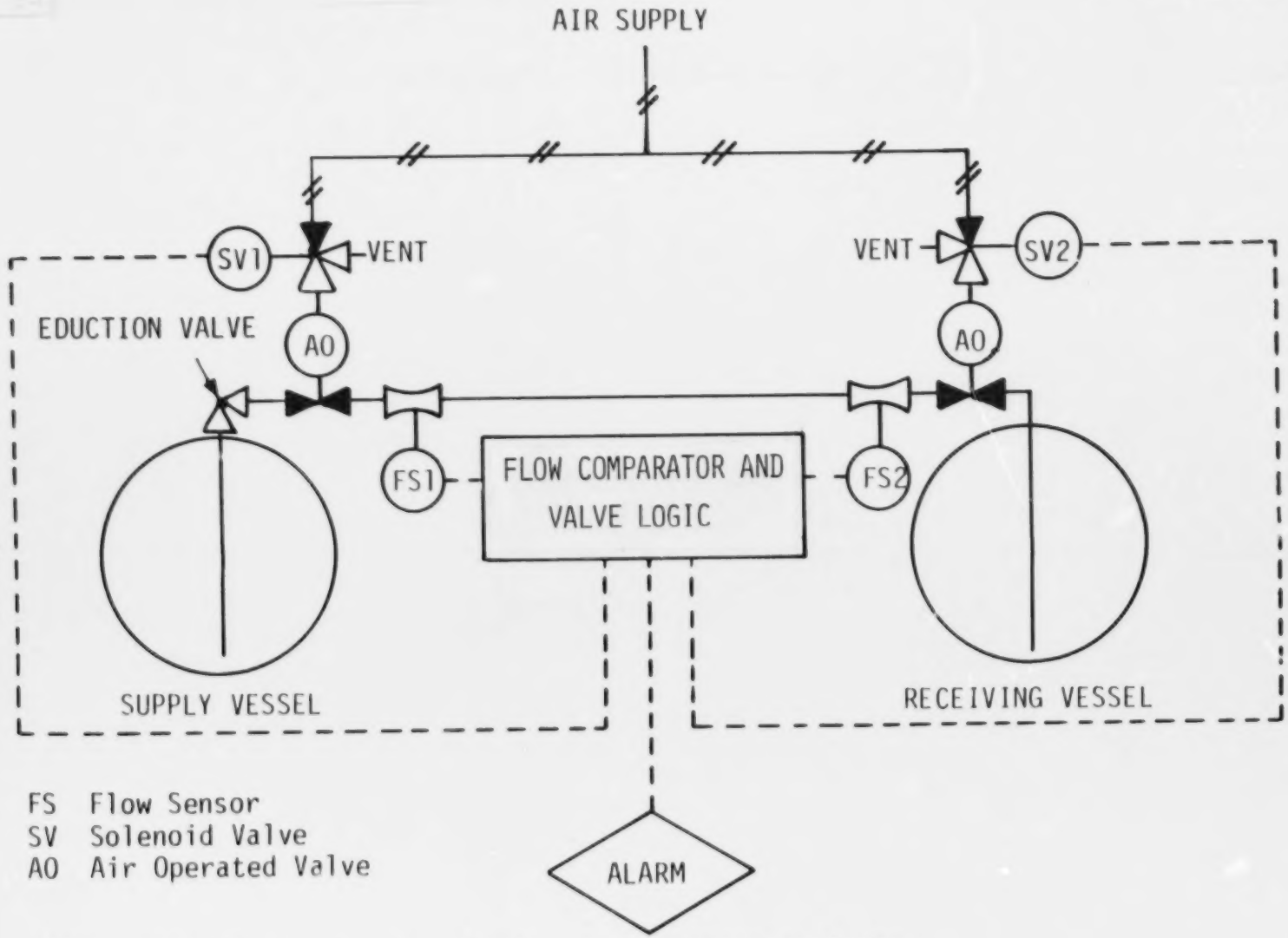
1. Automatic valve closure when any of the conditions necessary for safe operation are not satisfied (e.g., valve operating air pressure or electrical power).

2. A procedure for verification of proper operation at any time during a transfer operation.

Selection of Components, Materials, and Techniques

The criteria for selection were reliability, compatibility with the material to be handled, off-the-shelf availability, cost, and (for the portable parts of the system) weight. As originally planned, the material to be handled during the use-demonstration phase was aniline. This, in turn, required that the electrical portions meet the National Electrical Code explosion-proof standards for Class 1, Division 1, Group C or D materials.

The selection of valves and actuators quickly converged upon pneumatically operated stainless steel ball valves. Gate and globe valves require motor driven actuators, resulting in a relatively slow acting actuator-valve combination that is heavier, and more expensive than the ball valve-pneumatic actuator combination. Solenoid actuators were available for the ball valves but were too heavy (over 60 lb) for portable use. Brass is incompatible with aniline and reliability



NOTE: All valves are shown in the de-energized position.

Figure 1. Basic concept of fail-safe transfer line.

considerations ruled out the use of aluminum. The pilot valve required for remote operation of the pneumatic actuator weighed less than one pound and was available in a compatible explosion-proof configuration.

Stainless steel was selected for the pipe fittings because of its superior reliability. Further, since no margin of safety was needed to compensate for corrosion, lighter weight pipe could be used.

The dominant criterion for the hose was reliability. A rubber impregnated, steel-reinforced steam hose was selected. This hose was essentially identical to those commonly used at the use-demonstration site for offloading aniline.

The flow measurement sensors evaluated for use in the shutdown system were, in order of increasing cost, thermistors, thermal probes, turbine flow meters, and venturi tubes with differential pressure gauges. Analysis indicated that any available thermistor with an envelope compatible with aniline would have too slow a time-constant to meet the leak detection objective. Thermal probes appeared to meet all criteria and were initially selected for the development phase. They subsequently proved unsuitable for reasons discussed below, and turbine flow meters were selected instead.

The thermal probe has a small (1-cm OD x 2-cm long) platinum sensor that faces the flow. The electrical resistance of the platinum varies with its temperature. The sensor is heated to a temperature on the order of 500 to 850 C by an electric current. The flow cools the sensor and the flow rate can be determined by measurement of the voltage required to maintain a constant current through the sensing element or by measuring the current required to maintain a constant voltage drop. Circuits were designed for both the constant voltage and constant currents modes and to convert the differences into digital signals that would be used to activate the shutdown mechanism.

The control module was designed with integrated circuits throughout for reliability and small size. Transistor-Transistor Logic (TTL) was selected because of its reliability.

ASSEMBLY AND DEVELOPMENT

The major hardware items were assembled and set up in a laboratory shop. A 200-gallon tank and a 2-horsepower pump were used to provide a flow through the system. A reducing tee with a needle valve and a ball valve in series was inserted between the flow meters to provide controlled leakage rates for test purposes. The electronics were "breadboarded" for easy access to test points, and special circuits for diagnostics and data acquisition were fabricated. Figure 2 shows the inlet assembly. The outlet assembly is identical except that the strainer is omitted.

The initial development tests showed that the thermal probes were

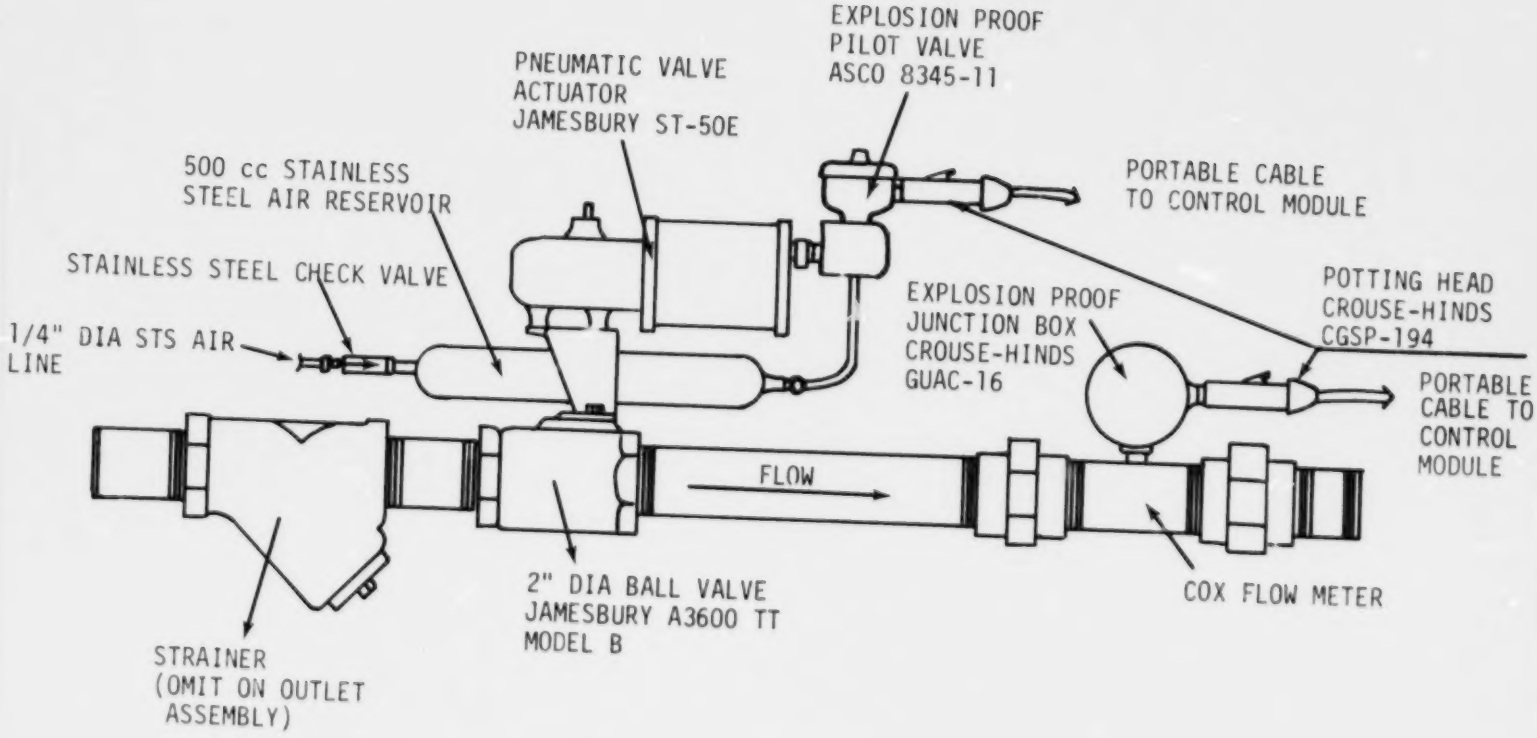


Figure 2. Inlet assembly.

unsuitable for the fluids of commerce. In a perfectly clear fluid, the probes are very accurate. However, in a "dirty" fluid, small particles of solid matter adhere to the quartz coating on the sensing element and alter the heat transfer characteristics. Even particles too small to be seen with the naked eye caused 10 to 20% changes in the indicated flow rates.

The thermal probe approach was discarded and the system was redesigned to use turbine flow meters. A turbine flow meter consists of a turbine wheel mounted axially in a short length of non-magnetic pipe. Two of the turbine blades have magnets inserted into their outer ends, and a coil on the outside of the pipe produces a low-level AC signal when the turbine rotates. The frequency of the signal is proportional to the flow rate over the operating range of the device. The accuracy of a typical good quality turbine flow meter is specified as $\pm$% of flow over its operating range. However, it was found that the relative differences between a pair of flow meters was less than 1%, which was maintained at flow rates much lower than those specified for absolute accuracy. Each flow meter has an arrow to indicate the flow direction for which it was calibrated. It was found that flow indication in the opposite direction was indistinguishable from the "proper" direction.

Flow meters are individually calibrated and it is unlikely that two will have identical K factors (the K factor is the number of alternating current cycles that will be generated per gallon of fluid passing through the meter). Further, it is necessary to provide compensation for unequal wear with prolonged usage. A rate multiplier circuit was built to use with the "fastest" (highest K factor) meter. The output of the rate multiplier circuit, f(out), is

$$f(out) = \frac{f(in) \times m}{4096}$$

where m is any desired integer between 0 and 4095. Thus, the meter indication can be synchronized to within 2.4 parts in 10,000.

A detailed understanding of the logic circuits (Appendix A) is not necessary for comprehension of the scope of the test and data acquisition effort. This effort involved the measurement of system outputs under various leak conditions so that operating strategies could be developed.

The basic logic circuit is an up-down counter. The up-down counter is actually set at 224 to start and the up and down counting is from this base number (224). The reason for setting at 224 is that the counter cannot count down from zero; and, hence, a reasonably high positive value must be used as the base setting; (224 is an arbitrary choice for this base). The count difference between the actual reading and 224 is called A.

The pulses from the inlet flow meter (normalized by the rate-multiplier circuit) cause the counter to count up; those from the

outlet flow meter cause it to count down. After a pre-set number of total pulses (a "frame") is received, the balance shown by the up-down counter is read, after which the up-down counter is reset to its base (224) for the start of the next frame.

The distribution of the magnitude of the balance was recorded for leak rates from 0 to 4% of flow. Experimentation showed that a "frame" of about 1,000 total pulses provides an adequate sample period to average out most naturally occurring variations in flow. The simplest implementation with digital logic resulted in a frame of 1,024 pulses corresponding to the passage of about 7.1 liters (1.88 gallons) through the system for the flow meters used.

Figure 3 shows the distribution of indicated flow imbalances for leak rates of zero and 1.5% of flow rate. A comparator circuit that accepts two binary numbers, A and B, and indicates whether A is greater than, equal to, or less than B was built. A is the excess or deficit of counts relative to the base (224) indicated by the up-down counter and B is a switch-selectable number. At the end of each frame, the comparator output was read. If, for example, the leak indicating threshhold, B, is set at 4, (actual number = 224 + 4 = 228) and A has a value of 6, (actual value = 224 + 6 = 230) the flow imbalance exceeds the switch-selected threshold, indicating a leak (more properly, the possibility of a leak). Under no-leak conditions, the up-down counter register rarely exceeded the base (224) by $\pm$ 4, but occasionally would read higher or lower. The anomalies were attributed to air bubbles, hose pulsations, and solid particles.

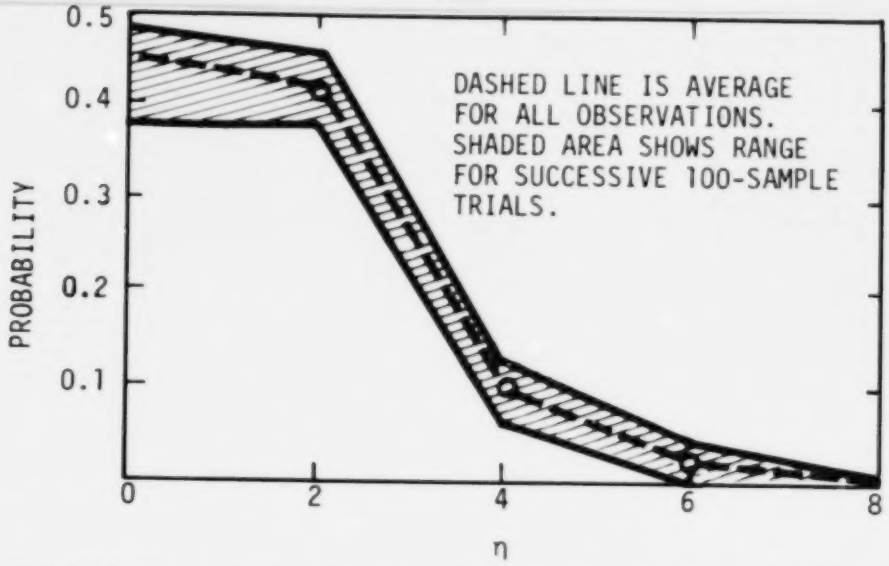
The system was then operated with various leak rates and values of B. The ratio of leak to normal indications, the number of successive leak indications occurring between two normal indications, and the number of successive normal indications occurring between two leak indications were recorded and their distributions determined.

These data formed the design basis for the balance of the circuitry.

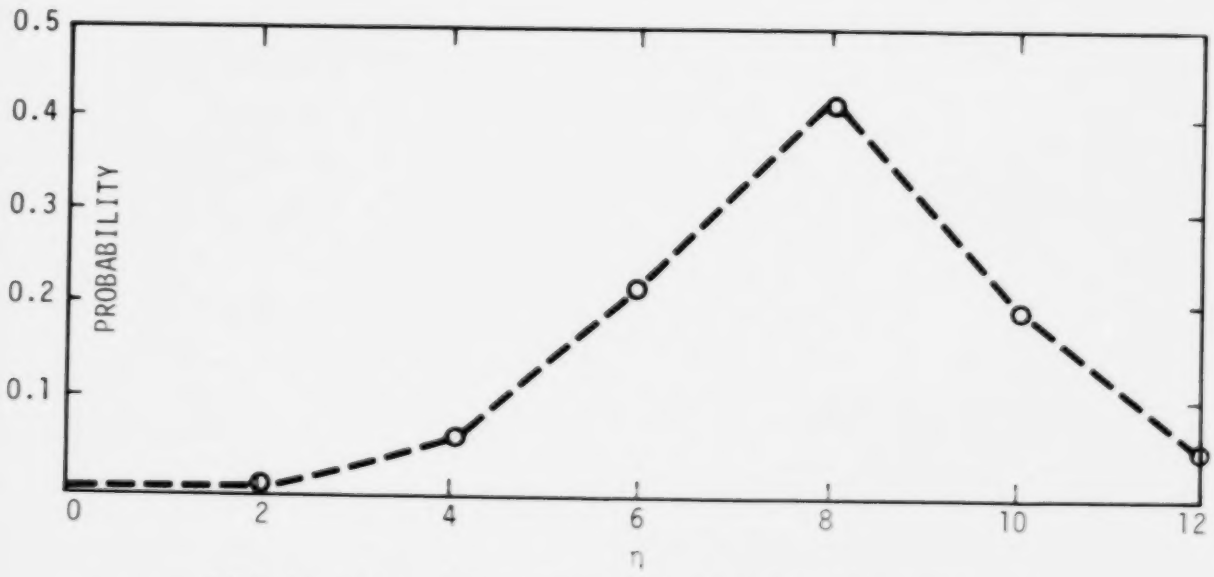
Analysis of the data showed that the reliable detection of small leaks (less than 2% of flow) could not be done on a single frame indication without a high false alarm rate. By increasing the number of frames used to conclude that a leak existed, the false alarm rate could be reduced. The penalty imposed was an increased time duration for the leak to exist before shutdown.

An additional counter register circuit was added. The count, C, displayed on the decision point shutdown activating counter register increased each time the comparator output (based on 224) indicated a leak (A>B). Further, the register was cleared to zero each time that two successive normal (A=B or A<B) indications were received. The shut down circuit was activated whenever the C-counter reached a preselected count (selectable from 2 to 8).

The ability to select both a threshold value for leak indication and



PROBABILITY THAT METER OUTPUTS WILL DIFFER BY η COUNTS IN ONE FRAME UNDER NO LEAK CONDITIONS



SAME AS ABOVE, BUT WITH A 1.5% OF FLOW LEAK INTRODUCED

Figure 3. Distribution of flow imbalance indications, 0 and 1.5% leak rates.

a shutdown decision criterion permits configuring the system to reliably detect small leaks with minimum chance of false alarm or, for particularly hazardous materials, to accept a high false alarm rate in return for the assurance that a very small leak would cause rapid shutdown.

With the leak indication threshold (B) set at 4 and the decision point shutdown activating counter (C) set at 3, the introduction of a 1% leak caused rapid shutdown. At a 6 liters/sec (100 GPM) flow rate, the fluid loss before shutdown was between 250 and 500 ml (1/2 to 1 pint), with most cases being at the lower end. False alarms under these settings were rare, but the time available for pilot-scale testing was not sufficiently long to gather statistically significant data.

The circuit further provided that a gross exceedance difference between the metered input and output flows caused an immediate shutdown.

Figure 4 shows the performance of the system for a leak rate of about 1% of flow for leak thresholds (B) of 2 and 4 counts, and a decision point (C) of 4.

The design which evolved is illustrated in the block diagram, Figure 5. An added feature, not discussed above, is the pilot valve current sensor. This feature is required only when a hazardous situation could be created by continued operation of the pump with no flow in the line. Severing of one of the cables to a pilot valve is a possibility. Should this occur, the affected pilot valve could cause closure of its valve, but the system would not shut down because both meters would sense the same (zero) flow. The pilot valve current sensor monitors the current to the pilot valves. When either pilot valve circuit shows "open", the sensor generates a signal that causes an alarm to sound, thereby alerting the operator to stop the pump. Alternatively, the signal can be used to directly activate the pump motor relay and automatically turn-off the pump.

OPERATING PERFORMANCE

There are three selectable operating parameters for the system:

Frame Size

The size of a frame is the number of total pulses received from both meters before making a comparison. The frame size is arbitrary, but the system is designed so that frame sizes of 256, 512, 1024 or 2048 can be selected to fit different situation requirements. (The frame size used in most tests was 1024).

Leak Threshold

The leak threshold is the difference between the number of pulses received from each flow meter in one frame. The selectable threshold is an even number beteen 0 and 14. (Because the frame size is an even number and is the aggregate of the pulses received from both meters, the difference cannot be an odd number.)

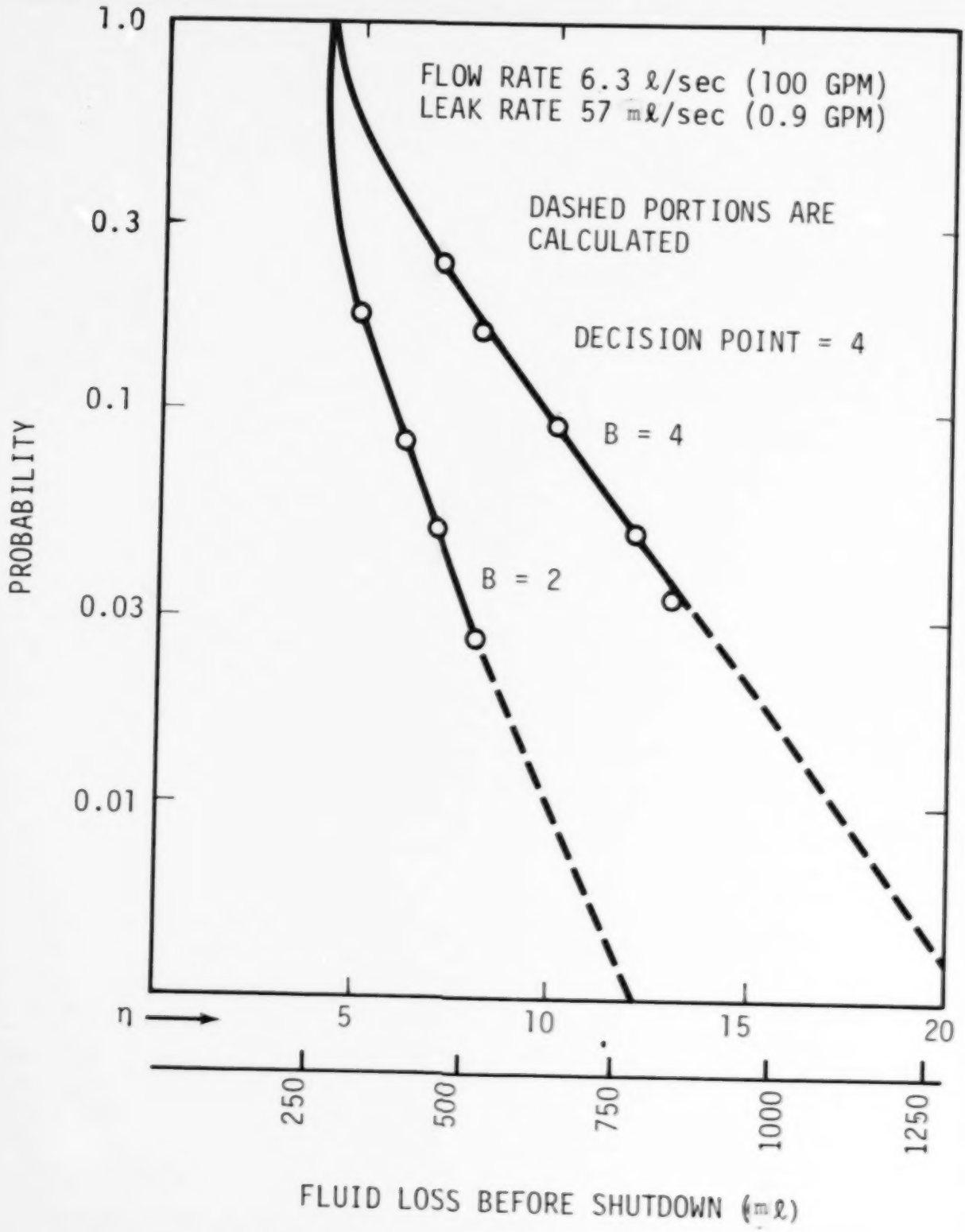


Figure 4. Probability that flow will continue for n frames after introduction of leak.

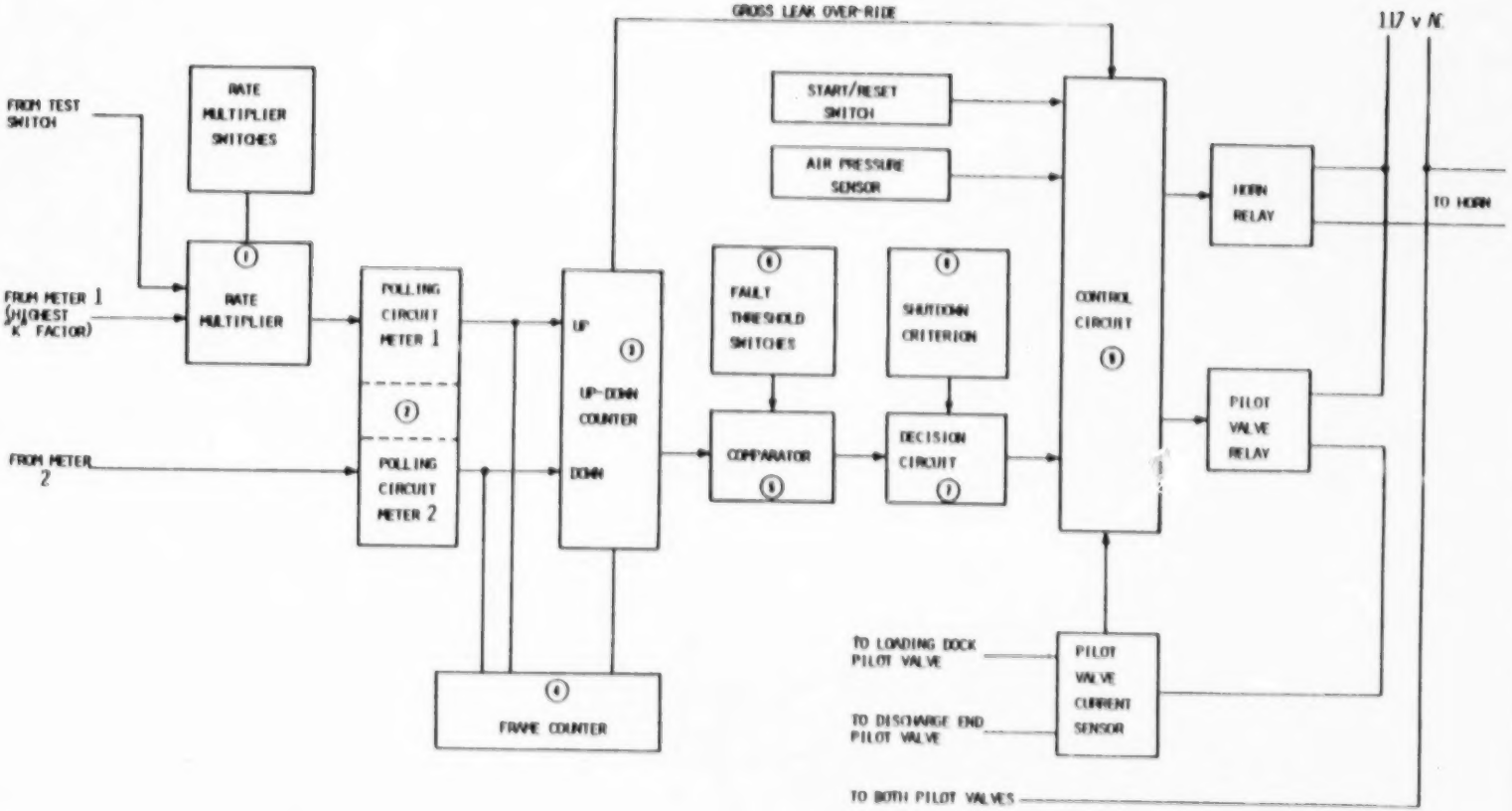


Figure 5. Fail-safe transfer line control module block diagram.

Decision Point

The decision point is the number of successive times the leak threshold must be exceeded, with no more than two normal indications between any two leak indications, to cause a shutdown.

Even with no leak present, there can be spurious differences between the meter indications. Indeed, 2-bit (count) differences are common (note that a 1-bit difference is not possible because of the even number frame size) and occur because the meters do not sense the same fluid volume at the same time. A gas bubble passing through the inlet meter will not pass through the outlet meter for several seconds. Further, the transfer line is not rigid, and pulsations may create small flow differentials.

The selectable parameters, designed to reduce false alarms arising from fortuitous count differences, interact as follows:

a. Leak Threshold and Frame Size--The smaller the frame size, the greater the effect of intrinsic system errors. When the frame size is 1024 pulses, a 2-count error is the equivalent of an 0.2% leak indication. When the frame size is set at 512, the same error indicates the equivalent of an 0.4% leak. Thus, a larger frame size minimizes the effect of inherent errors. To reliably detect small leaks, however, a small value for the leak threshold is desirable. Analysis of data acquired during the development phase indicated that a frame size of 1024 was a good compromise. A frame size of 2048 would further minimize the effect of inherent errors, but would reduce the system response time to what was regarded as unacceptable.

b. Leak Threshold and Decision Point--A small value for the leak threshold increases the probability of detecting a small leak, but results in frequent leak indications when no leak is present. This sensitivity effect can be compensated by requiring that a larger number of leak indications be detected before a shutdown is effected. The two parameters can be used to trade off system sensitivity and false alarm rate.

The probability of detecting a leak of a given size for a specified leak threshold selection, and the probability of a false alarm, can be approximated from the binomial distribution using the single event probabilities shown in Figure 6 (these data are for a frame size of 1024). Observed performance during testing showed a false alarm rate several times higher than calculated. A possible explanation follows. It is probable that the phenomena that cause false indications persist for several seconds and, in that case, would have a greater effect when the line was in continuous operation (as was the case for the false alarm trials) than would be the case when the up-down counter was stopped at the end of each frame to permit recording of the differences.

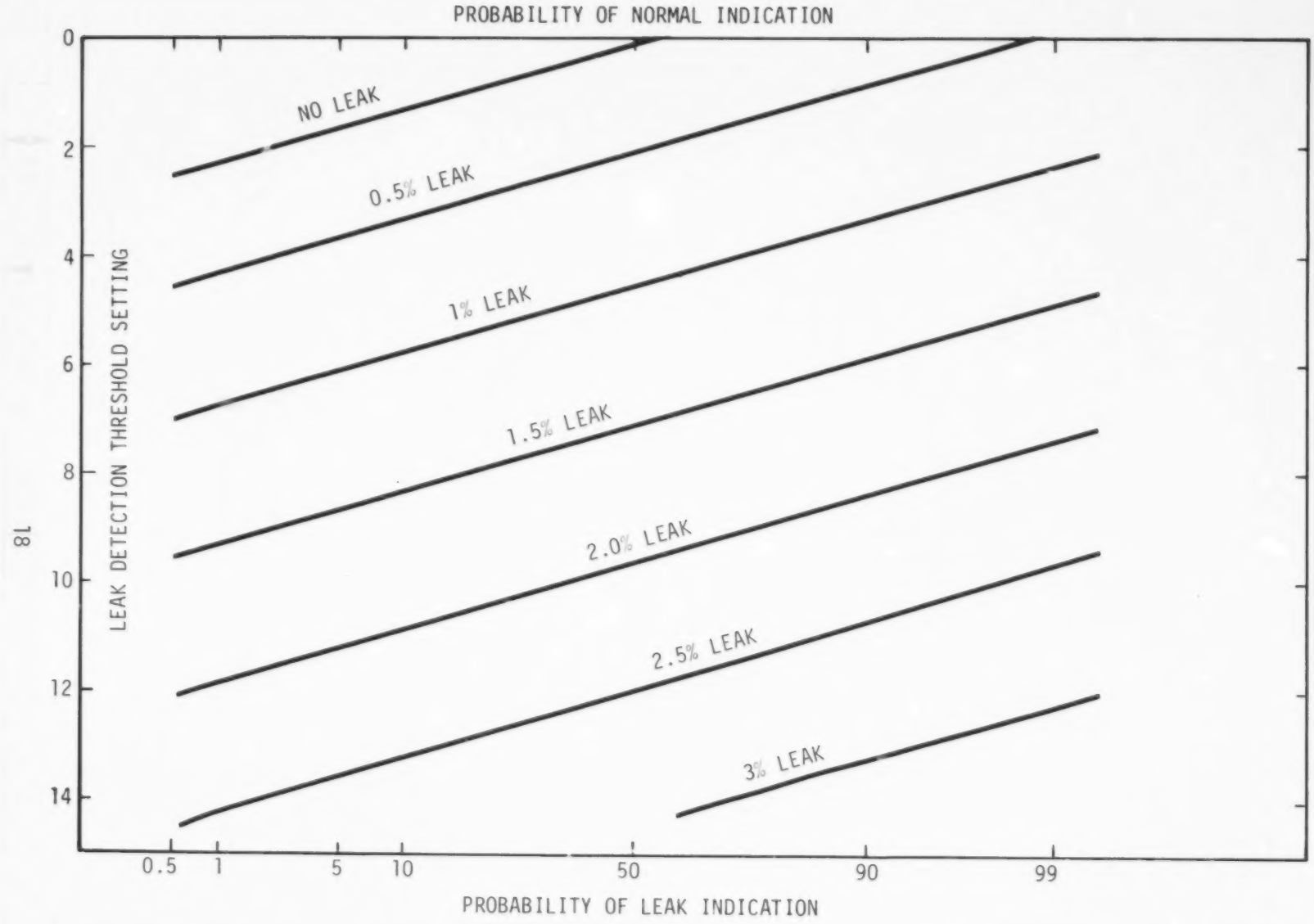


Figure 6. Approximate distribution of leak and no-leak indications with a frame size of 1024.

SECTION 6

USE-DEMONSTRATION TESTS

After the system was substantially completed, it was necessary to change the planned application. The fluid actually used in the tests was TAMOL-L concentrate, an aqueous solution of the sodium salt of napthalene sulfonic acid. The testing site was the Goodyear synthetic rubber plant, Houston, Texas. The system was installed by Goodyear personnel at the TAMOL-L concentrate storage tank site. Offloading stations for both tank cars and tank trucks were in the immediate vicinity of the tank. However, an expansion of the plant was in progress and access to the truck offloading stations was blocked. Consequently, only tank cars were offloaded. A total of seven tank cars, with an average load of 8,000 gallons each, were offloaded in six operations. No actual leaks were encountered. During the third unloading operation, a small leak was induced by loosening a pipe coupling at the point where the hose was attached to the outlet (storage tank) exit. The line shut down automatically within eight seconds. It is estimated that about one pint of fluid was lost before shutdown.

Significant difficulties were encountered in the use-demonstration tests, all attributable to the nature of the material handled. TAMOL-L contains over 50% dissolved solids. On prolonged exposure to the atmosphere the vehicle (water) evaporates, leaving a residue that varies from solid to semi-solid. When the transfer line was not completely purged after each use, the residual material dried out leaving a coating of solids on the internal surfaces. Upon reuse of the line, the fresh fluid caused pieces of the solid material to slough off, fouling the outlet flow meter.

A period of from two to fifteen minutes of flow, depending on the temperature of the fresh fluid and the degree of solidification of that which coated the internal surfaces, was usually required to establish trouble-free operation.

At the outset of one offloading operation, the system would not function. The flow meters were opened for inspection and it was found that the outlet flow meter was fouled with an amber, transparent crystal-like material. Neither TAMOL-L nor water would dissolve the material, indicating that it was not the residue from a previous TAMOL-L offloading. It was finally removed with steam. The flow meter was disassembled, cleaned, and reassembled and its calibration was checked using the internal circuits provided for this purpose (described in Appendix A). The calibration had changed slightly but, about ten minutes

after the flow had been resumed, the system calibration was back to its original setting. It is surmised that the transfer hose had been used for another material and that the residue of that material, on combining with the TAMOL-L, formed a solid.

On one occasion, the tank car sump was badly fouled with what appeared to be flakes of corroded metal. Immediately upon opening the tank car valve, the filter on the inlet assembly clogged. It was necessary to stop the unloading operation to clean the filter and to clear the sump by draining some of the fluid into buckets.

It was anticipated that the relatively bulky inlet assembly would be difficult to handle when the system was being connected to a tank car. A skid-mounted frame, which permitted positioning the assembly to any particular height and angle, was fabricated to facilitate handling. The pipe fitters at the Goodyear plant quickly devised a "universal joint", using two elbows, which made connection simple and rapid. The frame was discarded after the first use. The workmen considered that connection of the system to the tank car involved little more effort than the connection of a standard hose.

In general, the use-test period was successful in that it demonstrated that the system did not impose any significant increase in labor burden or cause unacceptable inconvenience during its use. However, the nature of the material handled created problems which would require an additional step--flushing the system with water--after each transfer, unless the transfers took place immediately (one after another).

REFERENCES

1. Buckley, J. L., and S. A. Wiener. Hazardous Materials Spills: A Documentation and Analysis of Historical Data. EPA-600/2-78-066. Factory Mutual Research Corporation Contract 68-03-0317 with the U.S. Environmental Protection Agency, 1978.

2. Unpublished analysis of data from the Pollution Incident Reporting System (PIRS) obtained through the courtesy of D. Boyd, USCG, 1976.

3. Mastandrea, J. R., J. A. Simmons, K. J. Gilbert, and P. B. Kimball. Deepwater Port Inspection Methods and Procedures. SAI CG-D-31-78. Contract DOT-CG-60670-A with U. S. Coast Guard, 1978.

4. National Electrical Code, 1971. NFPA 70-1971; ANSI CI-1971, National Fire Protection Association.

APPENDIX A

CIRCUIT DESCRIPTIONS

The input to the control circuits are the pulses from the flow meters. Once flow is established, operation is fully automatic in response to the settings of the internal adjustments.

The operator has access to only these controls:

1. An on-off switch for the 110-V AC power. With this switch in the "off" position, the valves at each end of the transfer line are closed and cannot be opened by operator action.

2. A start-reset push-button switch. When this switch is pressed, the valves are opened and the monitoring circuits are disabled. The operator must hold this switch "in" until flow is established--about 5 to 10 seconds.

3. A test push-button switch. Depressing this switch simulates a leak. It is used to test the response of the system.

The circuit descriptions which follow cover the three circuit boards: the meter board, the control board, and the pilot valve sensor board.

METER CIRCUIT BOARD

Referring to Figure A-1, the meter outputs are buffered by Schmitt-trigger gates, with the meter having the highest K factor (number of pulses per gallon) designated M1, and the other M2. M1 is routed to a 12-bit rate multiplier. The output of the rate multiplier is m/4096 times the input rate. Ten switches permit setting m at any value from 3072 to 4095 in unit increments. These switches are set to reduce the number of pulses from M1 to equal those from M2 for the same flow.

The test switch inverts the most significant bit of m, thereby permitting a test of the system shutdown response.

An oscillator and flip-flop produce a two-phase clock signal at a rate of about 200 kHz. Incoming pulses from M1 and M2 are stored in flip-flops (used as one-bit storage registers), which are alternately "read". When a pulse from M1 sets the flip-flop, it will be read during

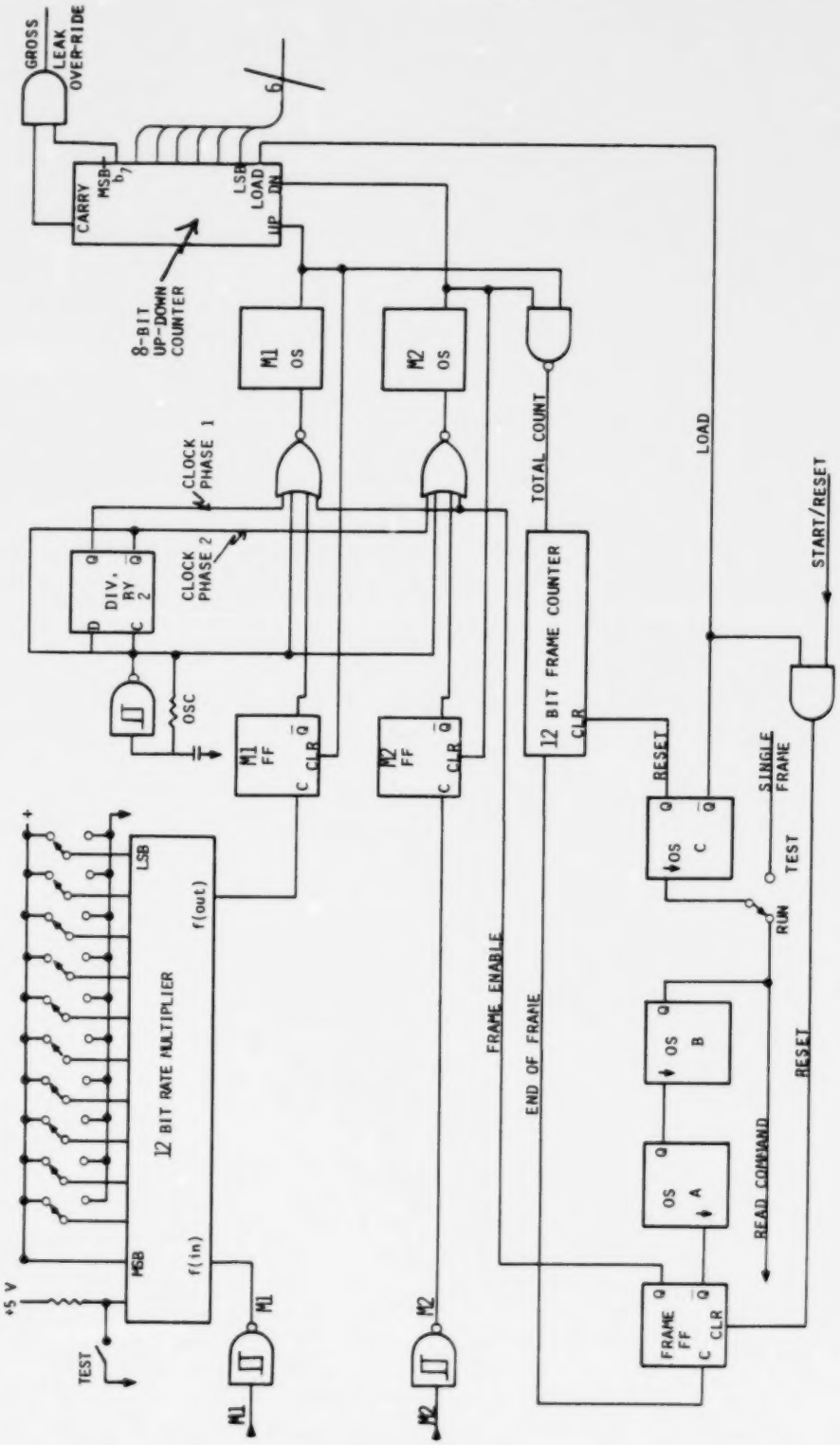


Figure A-1. Simplified logic diagram, meter board.

the phase 1 cycle of the clock, causing the M1 one-shot* to output a pulse. This pulse clears the flip-flop and causes the up-down counter to be incremented. Pulses from M2 are read on the phase 2 cycle of the clock and cause the up-down counter to be decremented.

Since the minimum interval between input pulses is about 400 times the interval between reading the flip-flops, no pulses will be lost.

The pulse count from both meters is routed to a 12-bit frame counter which can be set to output a pulse after 256, 512, 1024, or 2048 counts. 1024 was found to be the most suitable. When the frame count equals the pre-set value, the end-of-frame signal from the frame counter sets the frame flip-flop which disables the meter input counting gates and triggers one-shot "A" (Figure A-1). The falling edge of the pulse from one-shot "A" triggers one-shot "B" which sends a read command to the control board. The time constant of one-shot "A" is set to compensate for the settling time of comparators on the control board. The falling edge of one-shot "B" triggers one-shot "C"; resets the frame counter to zero, loads the up-down counter to its design preset value, and clears the frame flip-flop, thereby starting a new frame. The entire sequence from end-of-frame to start of a new frame takes less than 5 μ sec. Any meter pulses received during this sequence are stored in the respective meter input flip-flops.

The eight bit up-down counter starts each frame with a binary count of 11100000 (224), and the six least significant bits are routed to the control board.

Criteria for determining that a leak exists are set by switches and a patchable decision point on the control board. However, these criteria are optimized for the presence of small leaks and may require several frame intervals to effect a shutdown. To cause immediate shutdown in the event of a large leak (>6.5%), the carry and seventh bit outputs of the up-down counter are gated to create a "gross leak override" signal. The carry output will go "low" whenever the "up" count is 31 greater than the "down" count, and the seventh bit will go "low" whenever the "down" count is 32 greater than the "up" count.

A run-test switch is provided for system calibration. In the test position, a frame is initiated by toggling a "single frame" switch (not shown), but the up-down counter output is held at the end of each frame.

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* A one-shot, or monostable multivibrator, outputs a pulse of pre-determined width in response to an input pulse. If the meter polling circuit did not use a one-shot (i.e., used the output of the NOR gate as the output signal), the pulse would be so short that the response of the up-down counter would not be guaranteed.

CONTROL CIRCUIT BOARD

The control circuit board is shown in Figure A-2. The outputs of the six lowest order bits from the up-down counter are routed to the A inputs of a pair of eight-bit comparators (each made up of two cascaded four-bit comparators). The two highest order A inputs of each comparator are strapped to a logical 1. Note: A & B have different definitions than in the text part of this report and in Fig. A-1.

The four lowest order bits of the B inputs are selected by threshold switches, with those to the high limit comparator being direct, and those to the low limit comparator being inverted. Setting the four switches sets the upper and lower limits for fault tolerance. Each comparator has two outputs: A>B and A<B (the A=B outputs are not used).

The comparator arrangement permits detection of an out-of-tolerance indication regardless of whether the up-down counter balance is higher or lower than its initial (preset value). Consider a case in which the threshold has been set at 4, and the up-down counter indicates an output 6 greater (a leak indication) than the preset value (224):

B setting for high limit comparator	(224+4)	11100100 (228)
A input for both comparators	(224+6)	11100110 (230)
B setting for low limit comparator	(224-4)	11011100 (220)

In each case, the A input to the comparators exceeds both B settings, (A>B) indicating a leak.

Now consider the same case when the up-down counter reads 6 less than its preset value:

B setting for high limit comparator	(224+4)	11100100 (228)
A input for both comparators	(224-6)	11011010 (218)
B setting for low limit comparator	(224-4)	11011100 (220)

In this case, the A input is less than either B setting, indicating a potential leak condition. When the up-down counter output differs from its preset value by a number less than that set by the threshold switches, the comparators (A vs. high B and A vs. low B) will disagree (the up-down counter output falls between the upper and lower bounds, e.g., high B=228, A=222, low B=220), indicating a normal condition.

The comparator outputs are decoded by four NAND* gates. At the end of each "frame", a read command enables these gates (two inverters are used in the enable signal to one of the gates to compensate for the delay through other gates) and either a fault or a normal signal is produced.

* A NAND (not AND) gate has an output of logical 1 (one) if any input is a logical 0 (zero). Its output is a logical 0 if all inputs are logical 1 (one).

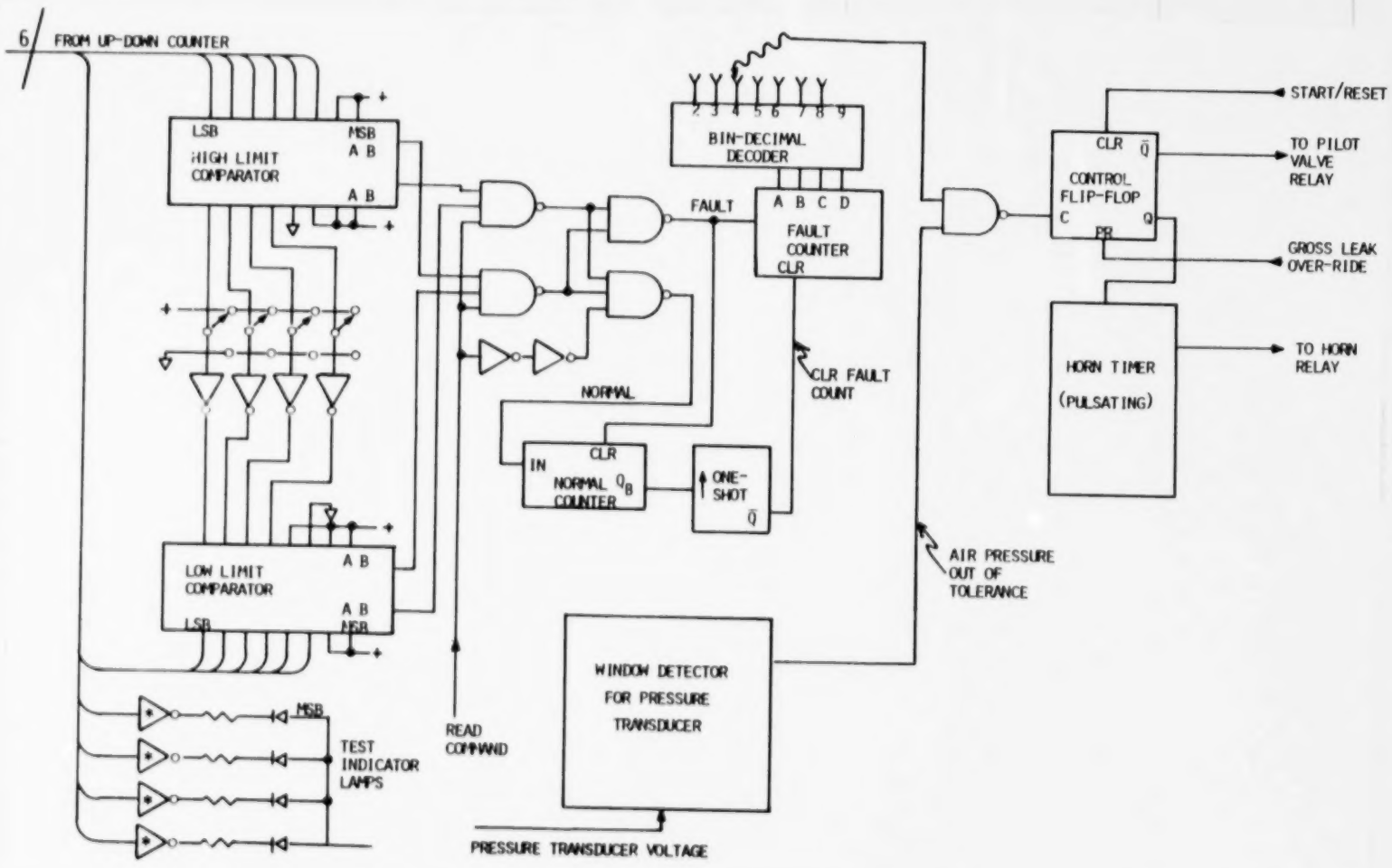

Figure A-2. Simplified logic diagram, control circuit board.

Any leak indication causes the fault counter to be incremented. The fault counter, in turn, drives a binary-to-decimal converter, whose output may be tapped at any integal value from 2 to 8 to provide a shut-down signal. (A leak indication clears the normal counter to zero).

Each normal indication increments the normal counter (configured as a divided-by-2 counter). Two successive normal indications cause it to trigger a one-shot, which in turn clears the leak indication counter to zero.

The shut-down signal is gated with an "air pressure out-of-tolerance" signal to a control flip-flop. A pressure transducer in the valve actuator air supply outputs a voltage proportional to pressure. This voltage is applied to a window detector whose output goes low whenever the pressure is too high or too low.

Either a shut-down signal or an out-of-tolerance-pressure signal will cause the control flip-flop to toggle. Its outputs will turn the pilot valve to "off", causing the valves to close, and will activate the horn timer, which causes the horn to pulsate (3 seconds on, 5 seconds off).

A gross leak over-ride, derived from the up-down counter, will also cause the control flip-flop to shut down the system and actuate the horn.

A start-reset switch, accessible to the operator, clears the control flip-flop and restores the system to operation. The switch must be held down until flow is established through both flow meters.

A system run-test switch (shown in Figure A-1), when set in the test position, actuates the power to four test indicator lamps and causes the logic to stop at the end of a frame. The lamps indicate the count of the up-down counter (the four least significant bits). This feature permits fine calibration of the rate multiplier setting.

CURRENT-SENSOR CIRCUIT BOARD

A simplified diagram of the current-sensor circuit is shown in Figure A-3. A series resistor is placed in the 110-V 60 Hz line to each pilot valve, and an optical isolator is placed across each resistor. When current is flowing to the pilot valve, the optical isolator triggers a retriggerable one-shot 60 times a second. The one-shot is timed for 50 to 60 msec and its output will remain high as long as there is current flowing to the pilot valve. Should the current be interrupted for more than four cycles (e.g., severed cable), the one-shot output will go low.

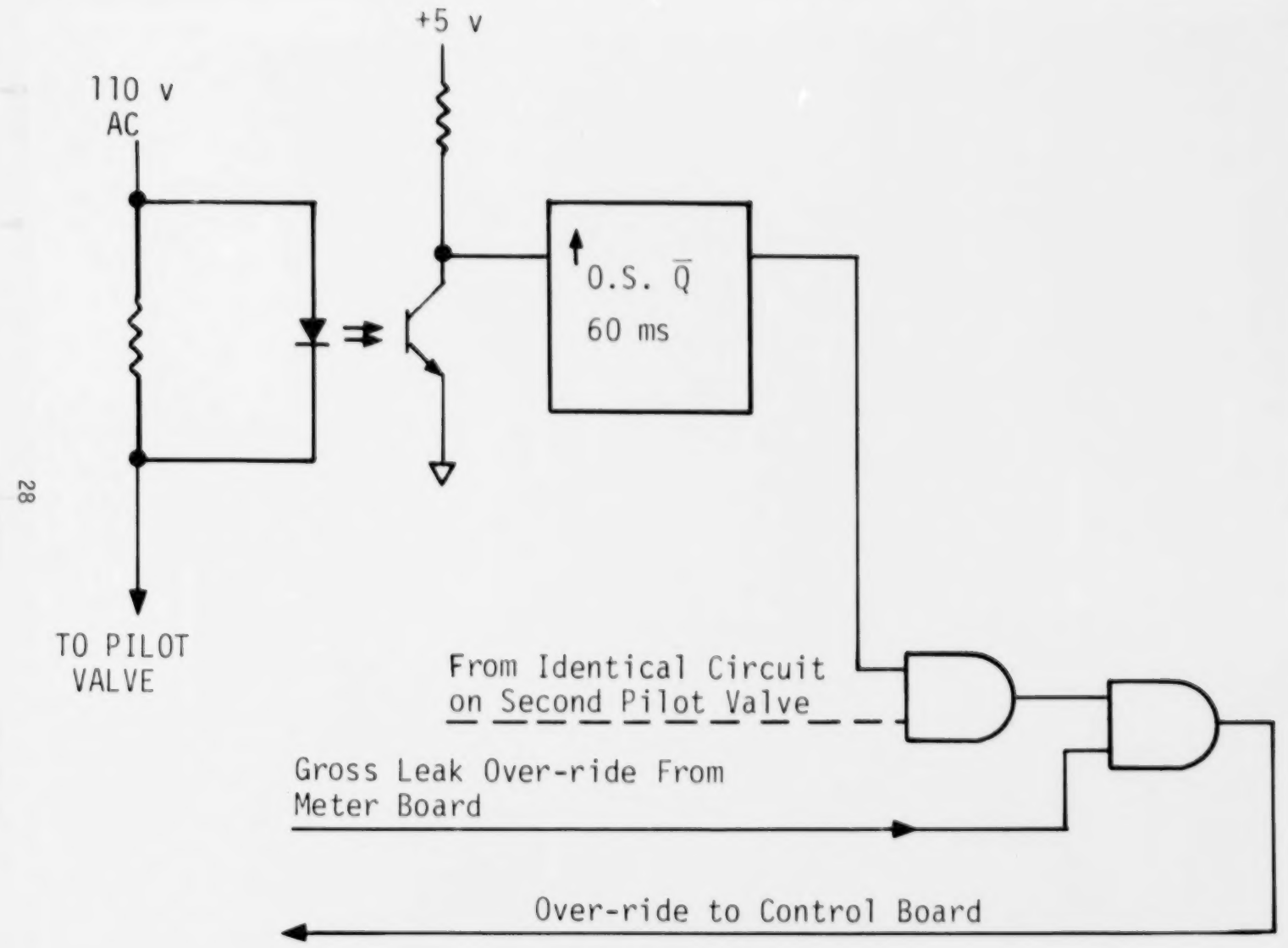

Figure A-3. Pilot valve current sensor.